CERTIFICATION OF TRANSLATION

Title of translated document::

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Original language of translated document: German

1. I hereby declare that my native language is German. English is my acquired language with 30 years of experience in general, technical, design and related fields.

2. To the best of my knowledge and belief, the attached is a true, accurate and complete English translation of the above-referenced German document.

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Drive Train for the Transmission of a Variable Power

The invention relates to a drive train for the transmission of a variable power at a variable input speed and a constant output speed. The invention relates, in particular, to stations having a variable power load, such as those encountered in the use of wind and water natural energy resources as well as other resources.

The use of wind energy is of interest, above all, for powers of greater than 1 MW. Furthermore, it is necessary to design the operational management of stations in such a way that a maximal power production occurs at a minimal dynamic load. In order to design the efficiency of the entire system in an optimal way, both during the phase when the unit is started up as well as during the operating phase and during standstill, a speed control for the operating machine is required, which can also be assisted in certain areas by additional kinds of control (e.g., positional adjustment of the rotor blades).

To be presented in the following, therefore, by way of wind power stations as example, is the problem of a time-variable power transmission, particularly in the case of an input speed that changes in time and a corresponding torque that changes in time, when, as secondary condition for the power transmission, an output speed that is essentially constant in time is required.

The operation of a wind power station is characteristic of the problem posed above for the reason that the electric power generated by the wind power station is fed into a power grid network that has a fixed network frequency. Because the network frequency represents the primary quantity for stabilizing and controlling the network, a prerequisite for a direct coupling of the generator of the wind power station is that it be supplied by the drive train at a constant speed. Such wind power stations are also referred to as fixed-speed wind power stations.

Conventionally used in such a case for fixed-speed wind power stations have been asynchronous generators, which, on account of the principle-governed slip, can be interconnected with a grid network in a simple way.

In contrast to the system requirement for wind power stations of a constant output speed on the drive train is the power input, which varies in time owing to the fluctuating wind situations. This problem is further aggravated by the mechanical power conversion of the kinetic energy of the air flow into the kinetic energy of the rotor motion, which is a characteristic inherent to the system. In the case of a fixed-speed wind power station, a specific rotor frequency or a few rotor frequencies is or are defined. More than one rotor frequency is possible only when a pole-changing generator is used or when different generators are used. In this case, the desired rotational speed of the rotor is conventionally attained by adjusting the angle of the rotor blades, this also being referred to as pitch control.

A drawback of fixed-speed wind power stations is the fact that, for partial loads, which occur commonly for typical wind situations, operation can occur only at reduced efficiency.

If a wind power station is operated at variable speed in the partial-load region, there exists the possibility of designing a drive train with either variable or constant output speed. In either case, the output power also varies in time on account of the time-variable torque.

For wind power stations, the first case leads to the use of frequency converters having a direct current link. However, this approach detours away from the problem posed here and, in particular, is encumbered with additional problems, such as a strong network feedback in connection with an increased harmonic load and high reactive powers.

The second approach, namely, coupling a variable rotor speed of the wind power station with a constant generator speed, corresponds to the subject presented here of a drive train for the transmission of a variable power at a variable input speed and a constant output speed. The known solutions of this problem, particularly for wind

power stations, employ a superimposing gear unit in the drive train, which is used for splitting or superimposing the mechanical power. Known in the case of fixed-speed wind power stations are only two approaches that are based on this and are used for keeping the generator frequency constant.

In the first system, the input power is distributed via the superimposing gear unit to a large generator and a small servomotor, with approximately 30% of the input power usually being transmitted to the servomotor. The generator is coupled to the power network at fixed frequency, while the servomotor is connected to the network via a frequency converter. For stabilization of the generator speed, the servomotor is operated either as a motor or as a generator. This system is also not free of feedback for the power network. Furthermore, such a system can be controlled only with difficulty and has, as power storage, essentially only the inert mass of the drive train and of the rotor. In addition, the investment costs are relatively high on account of the use of frequency converters.

In the second system, which operates in a hydrostatic manner, hydraulic motors and pumps are used in place of the electric servomotor. Here, too, the problem of a difficult control characteristic arises, in particular a sluggish response behavior and relevant dead times as well as strong nonlinearities. Moreover, the hydraulic system components present a drawback due to their design cost and their weight.

Summarized in the following table are the different known controls of the effective power of wind power stations that have been presented:

	Generator with converter	**Generator with converter and fixed-ratio gear unit**			**Generator with superimposing gear unit**	
System type	Electronic	One-stage gear unit	Gear unit	Gear unit	With electric motor	With hydrostatics
Generator	permanently excited synchronous generator	synchronous generator	4/6 pole asynchronous or synchronous generator	4/6 pole double-fed asynchronous generator	4/6 pole asynchronous or synchronous generator	4/6 pole asynchronous or synchronous generator
Converter	PWM - VSI	PWM - VSI	PWM – VSI	PWM - VSI	-	-
Gear unit		planetary stage	planetary stage + spur stage	planetary stage + spur stage	planetary stage + superimposing gear stage	planetary stage + superimposing gear stage
Control	rotor blades, speed	rotor blades, speed	rotor blades, slip pole change	throttling of the speed	rotor blades, speed	rotor blades, speed

The invention is based on the problem of designing a drive train for the transmission of a variable power in such a way that a power input can be loaded at essentially constant speed, so that the transmission process proceeds at a high efficiency and jerks in the drive train are minimized. Furthermore, a short-time energy storage is to be designed in the drive train in order to improve the control characteristic of the system. In addition to this, the number of components involved and the investment costs are to be kept at a low level.

This problem is solved by the features of claim 1.

The principle of the invention leads to a very good efficiency. In the case of wind power stations, the drive train of the invention leads, even for an uneven wind profile

and the different rotor speeds associated therewith, to a generator speed that is at a nearly uniform level.

Up to now, various adjustment and control possibilities with greater and lesser influence on the efficiency have been known for wind power stations:

- setting of the rotor blade angle,
- variable speed of the generator,
- slip control,
- throttling of the speed of the generator,
- changing the pole number, and
- speed control in the superimposing gear unit.

For the mechanism of operation of the speed control in accordance with the invention, it is possible to implement a combination of existing adjustment and control possibilities – for example, the setting of the rotor blade angle and the speed control in the superimposing gear unit. In the process, the rotor of the wind power station is always operated along its optimal characteristic curve (optimal efficiency) and a constant speed is delivered at the generator.

The invention is explained in greater detail on the basis of drawings. In them, the following is depicted in detail:

Fig. 1 is a schematic depiction of a power-split wind power station in accordance with the invention, having a hydrodynamic circuit.

Fig. 2 shows a graph that illustrates the efficiency and the output power of a hydrodynamic power-split transmission.

Fig. 3 shows the wind profile of a unit as per the invention as well as the corresponding rotor speed.

Fig. 4 depicts the effective power of a wind power station.

Fig. 5 illustrates a control for optimum power output of the rotor.

The rotor power p_R of a wind power station is related in approximation to the wind speed v_W as follows:

$$p_R = k \; c_P(v_W, \omega_R, \beta)\, v^3_W$$

Here, k comprises various constants, such as, for example, the blade geometry and the density of the air. Furthermore, c_P represents the performance coefficient, which, in turn, as shown, depends on the wind speed v_W, the rotor speed ω_R, and the pitch angle β. This performance coefficient is characterized by a global maximum, which shifts to higher rotor speeds ω_R as the wind speed v_W increases.

Fig. 2 shows this relation by way of the depiction of the effective power of a wind power station taking into consideration various wind speeds. Characteristic is the shift of the optimal rotor speed to higher values at increasing wind speed. A variable-speed station can accordingly be driven at optimal power performances in each case depending on the available wind speed.

Typically, wind power stations are laid out for specific nominal powers linked to a nominal speed. For wind power above this threshold value, a power limitation takes place, either through pitch control or through stall control, so that, for the variable-speed operation of a wind power station, the partial-load operation is of particular importance.

The drive train of the invention has a very good efficiency for transmission over the entire range of speeds, reference being made for this to the design example depicted in Fig. 10, for which a maximum transmitted power of up to 2.5 MW in a drive-speed range of n = 10 - 18 rpm at a constant output speed of n = 1500 rpm was calculated.

For wind power stations having a drive train of the invention, the following control functions or operating states are to be taken into account depending on the wind:

- switching on and switching off,
- braking of the rotors,
- operation at varying wind speeds, and
- operation at constant wind speeds around an optimal point of operation.

A variable-speed wind power station can be constructed advantageously with a drive train of the invention for the transmission of a variable power at a variable input speed and a constant output speed, which, in turn, is transmitted to a generator. To this end, Fig. 1 shows, in a schematically simplified manner, such a drive train 1 of the invention. It comprises schematically a rotor 1, a superimposing gear unit for power splitting, a speed reducing gear 2, a planetary gear 3 as well as a converter 4 and a generator 5 as further components.

Figure 1 accordingly discloses a power-split drive train comprising a hydrodynamic circuit which takes power from the main train respectively transmits the same retroactively onto the superimposed transmission. It may also be considered to design the drive train such that partial power is transmitted from the distributer via the converter. Thereby it is possible to use a hydrodynamic converter, a hydrodynamic coupling or a trilok converter as hydrodynamic circuit. In general, the hydrodynamic circuit at least to a certain degree may be controlled with regard to its power input and to its power output. In view of the present objective and particularly in view of the use in wind power units controllability of the said hydrodynamic components is essential.

Characteristic of a hydrodynamic circuit in the combination in accordance with the invention, which has a power-split transmission, is a certain softness in the reactivity. Under this, an adequate dampening without power loss is exploited for an advantageous control behavior, which results from the masses of the hydrodynamic circuit that are moved. In particular, short-time fluctuations in the system, such as those occurring for wind power stations due to shadow effects or during gusts, can thus be well cushioned by the system of the invention and this represents a substantial advantage from the point of view of control engineering for maintaining constant the output speed of the drive train of the invention.

Further characteristic of the arrangement of the invention is the fact that, through the use of at least one hydrodynamic circuit that exerts feedback on the power-split transmission, it is possible to realize an energy-storing effect, at least a short-term one. This, too, has an advantageous effect on the control characteristic of the drive train of the invention. As a support the drive train as per the invention may comprise an additional energy storing unit in the form of a buffer vessel acting during a short period of time.

Fig. 5 illustrates, in turn, by way of a wind power station as example, the flexible adaptation of an input speed of a drive train and thus a rotor speed that is optimally adapted to the wind, whereby, at the same time, a constant output speed (generator speed) is assumed. Depicted are different point of operations A, B, and C, which correspond to various performance coefficients together with the associated rotor speeds ω_C, ω_A, and ω_B.[1] At point A, the rotor withdraws from the air flow an optimal power. At point C, only a part of the possible rotor power is exploited and, consequently, the hydrodynamic circuit is controlled in such a way, in the power input from the main drive train and in the power delivered in the feedback to the power-split transmission, that the rotor is accelerated until it attains the optimal point of operation A. The control starting from the point of operation B takes place with an opposite sign. Accordingly, this corresponds to the control in an optimal point of operation at a wind speed that is assumed to be constant.

Furthermore, it is possible that a certain fluctuation in the wind occurs, through which the constant point of operation is shifted. An example of this is the point D, which, like the point A, lies on the curve of optimal power and corresponds to a lower wind speed. Accordingly, the drive train of the invention also makes it possible to adjust or control a time-variable input power with variability in time of the input speed.

Fig. 3 shows, to this end, a wind profile having a wind speed that fluctuates in time, which, in turn, is converted to an optimal rotor speed. In this process, a certain degree of smoothing takes place on account of the inertia of the mechanical components used, namely, the rotor, the gear unit, the hydrodynamic circuit, etc.

Generally understood in the framework of the idea of the invention of creating a drive train having a constant output speed is also such a system that keeps the output speed constant with a certain degree of precision. Certain deviations can be tolerated here. The deviations in this case can lie, for example, in the range of ± 10%, preferably ± 5%, and especially preferably ± 1% of the specified output speed. When wind power stations are used for generators that are strongly coupled with the distribution network, however, an especially high constancy of the output speed of at most ± 0.5% is preferred, which further supports the network being operated.

Further possibilities of applying a drive train in accordance with the invention beyond wind power ensue, for example, for special water power stations in which turbines that to be operated at a constant speed are employed. Such conditions can exist, for example, in current and tidal power stations or for special arrangements in sluice systems. In addition, it is conceivable to use the principle of the invention to transmit natural and thus time-variable energy sources, such as wave power, to an electric generator that requires a constant input speed.

Patent Claims

1. A drive train for the transmission of a variable power at variable input speed and a constant power output speed, comprising

1.1 a power-split transmission (5);

1.2 a hydrodynamic circuit;

1.3 a power receiver;

1.4 means for distributing the power from the power-split transmission to the hydrodynamic circuit while at the same time power is transmitted to the power-split transmission and to the power receiver at a selectable ratio.

2. Drive train according to claim 1, characterized in that the hydrodynamic circuit is a controllable converter.

3. Drive train according to claim 2, characterized in that the converter is a trilok converter.

4. Drive train according to claim 1, characterized in that the hydrodynamic circuit is a controllable coupling.

5. Drive train according to one of claims 1 to 4, characterized in that the hydrodynamic circuit is designed such that it may optionally operated as a break.

6. Drive train according to one of claims 1 to 5, characterized in that a short term energy storing unit is associated with the hydrodynamic circuit.

7. Hydrodynamic circuit according to one of claims 1 to 6, characterized in that the power receiver is a power machine in the form of an electrical generator.

8. Drive train according to one of claims 1 to 6, characterized in that there is a transmission arranged before or after the split power transmission.

Fig. 1

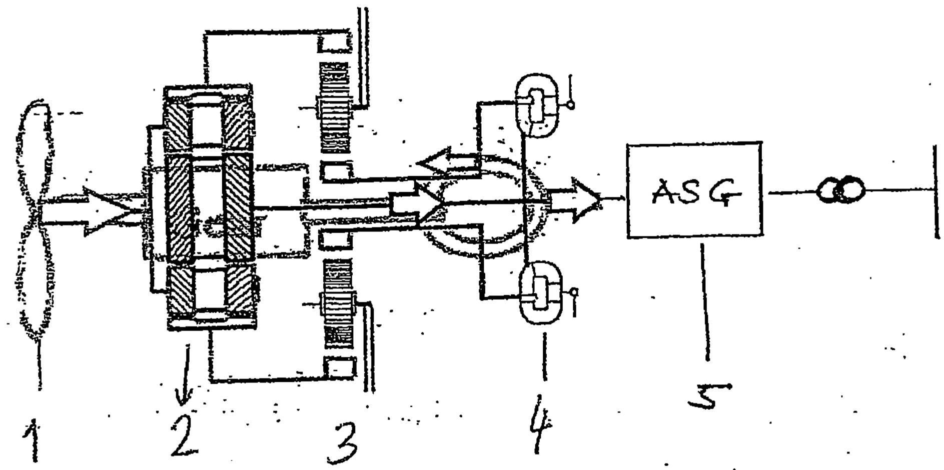
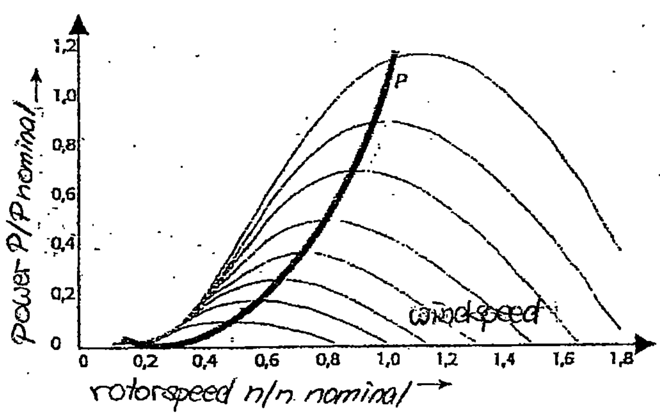

ASG
1
2
3
4
5

Fig. 2


Power P/Pnominal
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1,0
0,8
0,6
0,4
0,2
0
P
windspeed
0
0,2
0,4
0,6
0,8
1,0
1,2
1,4
1,6
1,8
rotorspeed n/n nominal

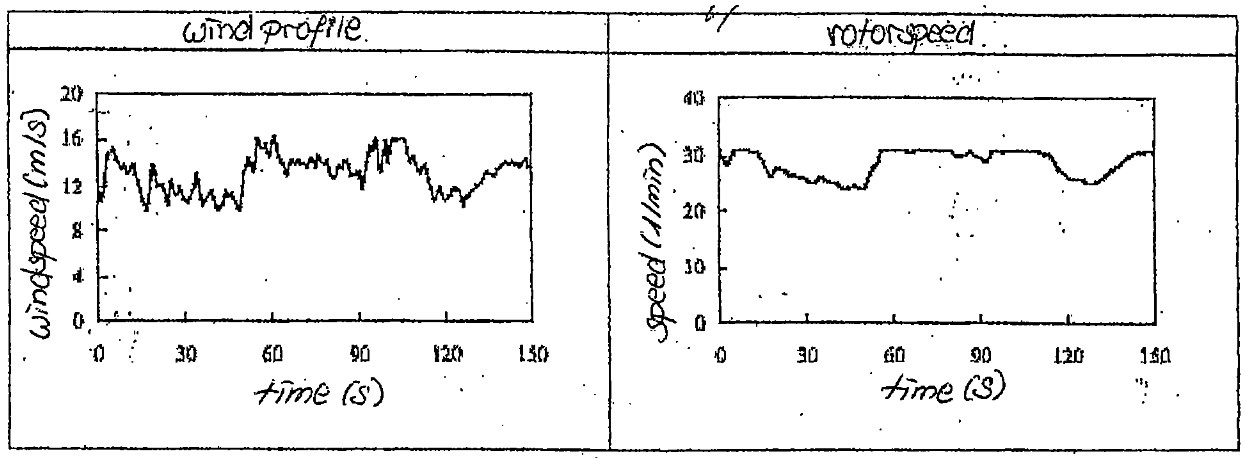
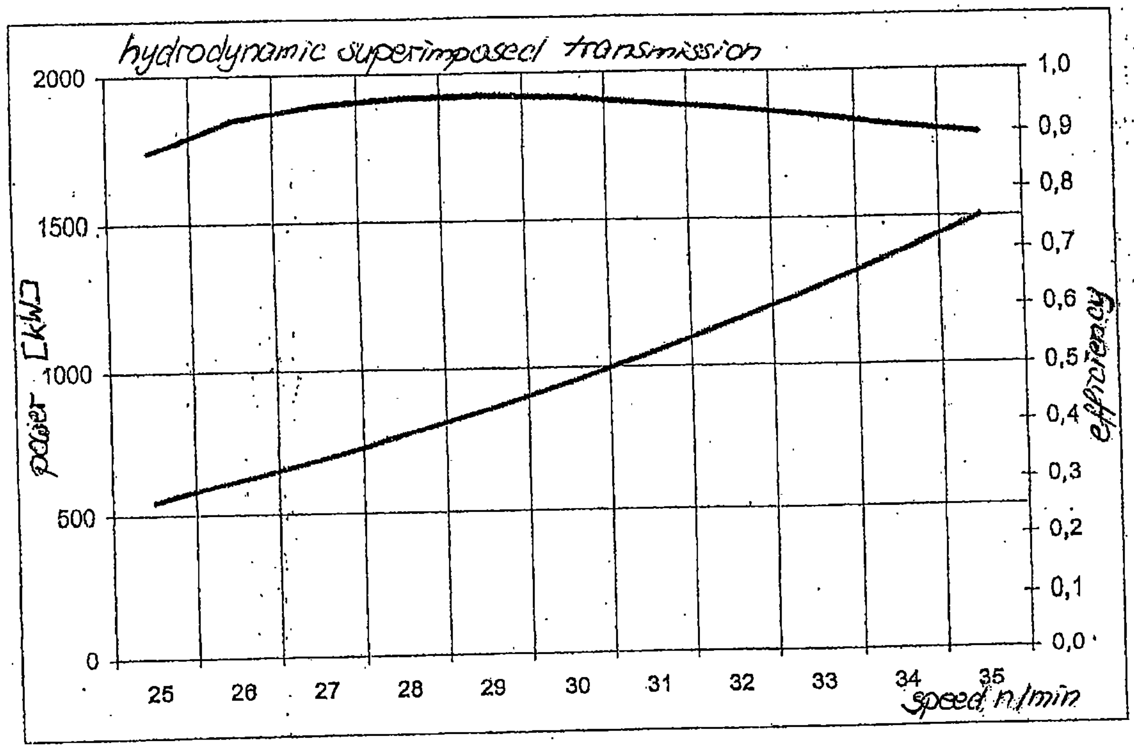

wind profile
rotorspeed
windspeed (m/s)
20
16
12
8
4
0
0
30
60
90
120
150
time (s)
speed (1/min)
40
30
20
10
0
0
30
60
90
120
150
time (s)

Fig. 3

Fig. 4


hydrodynamic superimposed transmission
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1500
1000
500
0
power [kW]
1,0
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
efficiency
25
26
27
28
29
30
31
32
33
34
35
speed n/min

Fig. 5